Triboluminescent Materials: Molecules that Bring their Own Energy

Things are really lighting up at Sandia. Literally. Through a research foundation, the Materials Chemistry group (8722) is developing a variety of materials that emit light upon fracture. This phenomenon, known as triboluminescence, was first reported more than four centuries ago by Sir Francis Bacon. The program is part of the functional organic materials initiative in the Materials Chemistry Department. Specifically, we are interested in materials that bring their own energy with them.

Triboluminescence Phenomenon Reported in Year 1605

Triboluminescence (TL) is a term that was coined in 1888 to describe light emission resulting from fracturing materials. The phenomenon was named from Greek prefix *tribo*, meaning "to rub." The term stuck and is used today to describe light emission from fractured or tribologically excited materials. Although the phenomenon was first reported in 1605, the mechanism by which light emission occurs is still not fully understood for all TL compounds. In many materials, for example sugar, TL emission results from dielectric breakdown of air, and is barely visible to the eye as a bluish light due to nitrogen luminescence. Some research groups correlate TL with noncentrosymmetric crystalline structures, and therefore piezoelectric materials, suggesting that charge separation among the fracture planes is necessary for light emission. Yet centrosymmetric materials can drive the triboluminescent event as well, in addition to many non-crystalline sources, including some metals.

The brightest TL materials known are based on chelates of europium (Eu) III complexes. We have recently developed new light-emitting TL materials (Fig. 1) that are as bright as the brightest known material reported in the literature, as well as other TL materials never before reported. When fractured, the bright red light emission from the europium luminescence is easily observable even in daylight.

Practical Applications

Only recently are there reports of using TL materials for practical applications. We are interested in these materials as "no-power" damage sensors as the materials are able to bring there own (light) energy with them. Sandia has developed two materials that embed TL crystals into polymeric matrices. SNL's first material, called FlashFoam (U.S patent No. 6,581,474), incorporates the Eu TL crystals into the cellular structure of a brittle polyurethane foam. The active TL material is distributed evenly throughout the structure and uniformly collapses when deformed at high rates. This allows for all of the TL material to respond in tandem to the mechanical event. As a result, the output sensitivity is many times greater than that achieved on a monolithic, full density structure that fractures only along a single crack. Figure 2 illustrates the impact response for a typical FlashFoam specimen. We used an optical fiber to gather a small fraction of the light emitted from the foam during the impact tests and transmit it to a photodiode or photomultiplier tube.

A second material developed, called ElastoBrite, uniformly incorporates the Eu TL material into common flexible elastomers (e.g., silicones). When the elastomer is subjected to mechanical stress, the strain energy is locally transmitted to the triboluminescent material

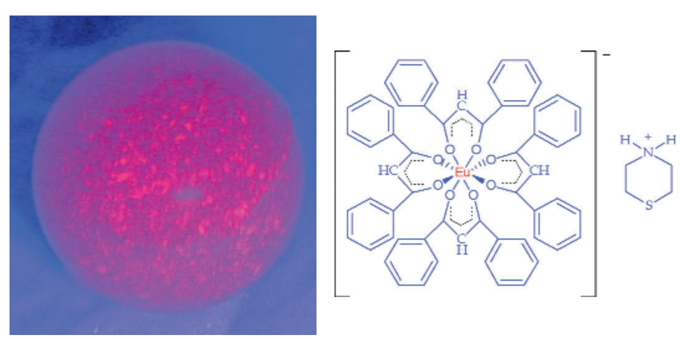

Figure 1. Rubber ball incorporating thiomorpholinium tetrakis (dibenzoyl-methanato) europate (in this case, excited by UV light rather than fracture).

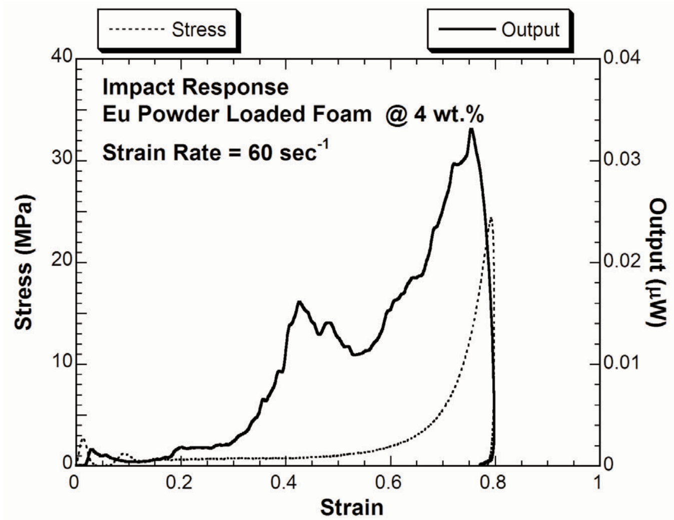

Figure 2. Impact response of a foam specimen containing 4 wt.% Eu powder.

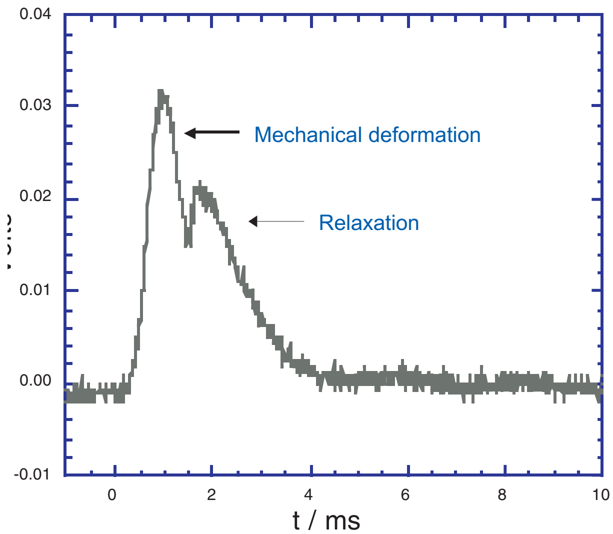

Figure 3. Two separate light events from elastomer deformation and relaxation.

causing the powder to experience shear and fracture. It is this deformation, subsequent shear and fracture that induces the TL response of the powder, resulting in red light emission. As the mechanical deformation relaxes and dissipates, the elastomer reconstitutes its shape, and a second light event occurs (see Fig. 3). Unlike FlashFoam, this material does not require structural damage to the elastomer to trigger light output, and is inherently reusable for many cycles.

Benefits of Composite Approach

Several benefits are derived from both of these composite approaches to TL materials: 1) they may be fabricated into any arbitrary shape, or 2) they may be molded in-situ to fill the free volume of existing structures, and 3) they can be tailored to fail at lower impact energy levels compared to solid materials.

Because the parent foam or elastomer is a structural material, in principle it can be incorporated into a wide variety of mechanical design components. Sensors that simply "report out" using their own internally stored energy can take us from wired interconnects to self-powered optical networks.

Team Members

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Jim McElhanon (8722) received his B.S. in chemistry from Quinnipiac College and Ph.D. in chemistry from the University of Connecticut.

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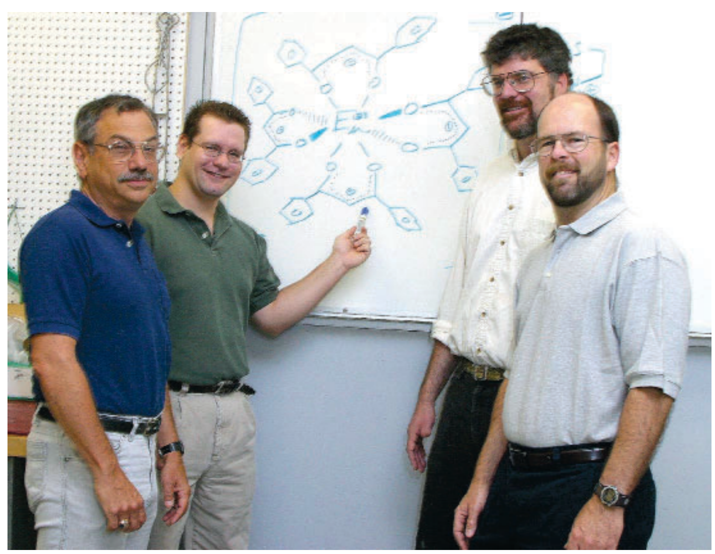

Team members (from left): Steven Goods (8725), Jim McElhanon (8722), Paul Dentinger, LeRoy Whinnery (8722), and Tom Zifer (8722) (not pictured).